**REPAIR GUIDE**
**continued**

CR 2

*Execution*
The contractor should demonstrate repointing on a test panel in an inconspicuous area of the building that includes all types of masonry, joint types, and problems to be encountered on the job. Usually a 3-foot by 6-foot test panel is sufficient. Once the test panel is approved, work can begin.

The joint is prepared by removing the mortar to a depth of 2 ½ times the width of the joints. For most masonry, this depth is ½ to 1 inch. Any loose or disintegrated mortar beyond this minimum depth should be removed. Care should be taken not to damage the existing adjacent masonry units. Loose material in the joints should be removed with a brush, and the joint flushed with a water stream.

The mortar is prepared by measuring all dry ingredients and mixing them together. When ready to use the mortar, add water to bring it to a consistency that is somewhat drier than conventional masonry mortar.

The joints should be damp, but with no standing water. Install new mortar only when temperature is between 4° and 95° F. During hot weather, repoint on the shady side of the building, or install netting over the scaffolding to provide shade. Mortar is packed into the joint in ¼-inch-thick layers, leaving no voids, until the joint is filled. Tool the joint to match the original mortar. If desired, after mortar has initially hardened, stipple with a brush to give a weathered appearance. Remove excess mortar from adjacent masonry using a bristle brush. Keep the pointing mortar damp for 2 to 3 days, using a fine-mist hand sprayer.

*Quality Assurance*
- Make sure that only damaged or deteriorated joints requiring it are repointed.
- Require samples of the repointing mortar to verify the mortar matches the original.
- Require test panels to verify the quality of workmanship and retain them throughout the job for comparison.
- Inspect joints after preparation to verify that enough old mortar has been removed.
- Make sure joints are dampened before application of new mortar.
- Make sure that joints are being tooled to match original appearance. Often, the corners of the masonry units are worn back and if the joints are completely filled to the surface, the joints will be considerably wider than original, ruining the appearance. If the corners of the masonry units are spalled or worn, the mortar will have to be slightly recessed in the joint to achieve the original appearance.

*Limitations*
The owner, consultant, and contractor should realize that repointing can be a time-consuming and expensive repair. (However, proper repointing is the only long-lasting repair for cracked or deteriorated mortar joints. A good repointing job can last up to 50 years.)

*References*

ASTM, 1997, *Standard Specification for Aggregate for Masonry Mortar, C144-97,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM, 1997, *Standard Specification for Portland Cement, C150-97a,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM, 1997, *Standard Specification for Hydrated Lime for Masonry Purposes, C207-97,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM, 1997, *Standard Specification for Mortar for Unit Masonry, C270-97,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ICBO, 1994, *Pointing of Unreinforced Masonry Walls*, Uniform Building Code Standard No. 24-9, International Conference of Building Officials, Whittier, California.

Mack, R.C., T.P Tiller, & J.S. Askins., 1980, *Preservations Briefs: 2 Repointing Mortar Joints in Historic Brick Buildings*, U. S. Depart of the Interior, Heritage Conservation and Recreation Service, Technical Preservation Services Division, U. S. Government Printing Office, Washington, D.C.

| | | | |
|---|---|---|---|
| | REPAIR GUIDE | **Repair Type:** | Cosmetic Repair<br>Structural Repair |
| CR 3/SR 1 | CRACK INJECTION - EPOXY | **Materials:** | Concrete<br>Reinforced Masonry |

*Purpose*

Crack injection consists of applying a structural binding agent into a crack for the purpose of filling the crack and adhering to the substrate material. Various types of materials and methods can be used for crack injection depending on the required performance. For concrete and fully-grouted, reinforced masonry walls, epoxy is typically injected into cracks under pressure.

*Repair Materials*

- ASTM Standard C881, Type I, low-viscosity grade epoxy.
- Other materials such as fine cementitious grout and urethanes can also be used for structural bonding.

*Equipment*

- Pressure injection machine with mixing nozzle at the tip capable of injecting with pressures of 300 psi.
- Porting devices installed with specialized drill bits.
- Equipment to monitor pressure and mixing.

*Execution*

Prior to injection, loose material should be removed from the cracks. Cracks can be injected through surface-mounted ports or into drilled entry ports, although surface-mounted ports are used by most contractors (Krauss et al., 1995). The injection ports are located along the length of the crack and should be spaced at a distance roughly equal to the thickness of the wall, depending on the viscosity of the material and the manufacturer's recommendations. Ports should be drilled with drills that prevent fines from remaining in the crack. When full-thickness repairs are required, it is beneficial to seal both surfaces of the wall along the crack, except for the entry ports. When epoxy injection is for cosmetic purposes or when less than full-thickness repairs are acceptable, the crack is sealed only on the injection side.

Before injecting, the epoxy should be pumped into a paper cup until the material appears to be completely mixed. Cracks are injected starting at the bottom of vertical and diagonal cracks, changing to the next port as the epoxy appears there. Splitting tubes can be used so that the epoxy can be pumped into multiple ports simultaneously. Previously injected ports should be sealed. If necessary, the surface is ground smooth to remove the surface seal and leakage after the epoxy has set. Grinding should not be started until the epoxy has cured.

*Quality Assurance*

Personnel experienced in epoxy injection should be used for the work. The mixing equipment should be evaluated before beginning the work to verify proper operation. Samples should be prepared and tested for consistency of the epoxy and bond strength. Twice daily during the epoxy work, the mix ratio should be tested to ensure it is within the manufacturer's tolerances. The mix test should be conducted at the pressures at which the work is being done.

The effectiveness of crack injection can be confirmed by alternative methods. These methods, however, only test the penetration of the epoxy into the cracks; they do not check the adequacy of the bond of the epoxy to the substrate.

Core holes can be drilled through the cracks after injection and visually examined to verify that the epoxy has penetrated the cracks. Typically, 2-inch diameter core holes are specified. The spacing of the core holes should be between 50 feet and 100 feet (Trout, 1991)

Nondestructive evaluation methods can be used to verify the effectiveness of the epoxy penetration (Guedelhoefer and Krauklis,1986).

**REPAIR GUIDE**
**continued**

CR 3/SR 1

*Limitations*
Moisture on the crack surface can reduce the bond of the epoxy to the crack faces. If the crack contains contaminants, it should be cleaned to remove both the contaminants and any moisture that will reduce the bond.

Crack widths as small as 0.002 inch in width can be injected with epoxy. Crack widths up to 0.012 inch can be tolerated in reinforced concrete in humid or moist air conditions (ACI, 1994a). A low-viscosity epoxy will not be effective for crack widths greater than 1/8 inch. For widths greater than 1/8 inch a medium-viscosity epoxy should be used. For surface crack widths greater than ¼ inch, epoxy pastes or gels should be used. For cracks that are wider at the surface, an epoxy paste can be applied at the surface and a low-viscosity epoxy injected through the cured paste to the smaller, interior cracks.

Epoxy injection can also restore the bond of reinforcing bars (French et al., 1990). For the epoxy to restore the bond, there needs to be a sufficient amount of surface cracking that intersects the debonded reinforcing for the epoxy to penetrate along the surface of the reinforcing bar.

The operator must be attentive to the amount of epoxy being injected relative to the spacing of the ports. A theoretical quantity of epoxy to be used can be calculated. Injection should stop if the amount required exceeds 50 percent more than the calculated amount (ACI, 1994b). This is particularly important when injecting reinforced masonry walls that may contain large voids. Excessive amounts of epoxy may also indicate that epoxy is leaking out through a crack or joint.

If the ports are spaced too far apart for the viscosity of the epoxy, the epoxy may harden before reaching the adjacent port. Conversely, if the ports are too closely spaced, the epoxy may not reach the full thickness of the wall before bleeding out of the adjacent port.

After finding satisfactory penetration from a number of cores, the spacing of subsequent cores can by increased, provided the same operator, epoxy, and equipment are used and the environmental and structural conditions remain the same.

Nondestructive evaluation (NDE) methods should be used on the cracked wall prior to repairs and should be calibrated for the repaired condition using undamaged sections of wall. However, NDE methods may not be effective in evaluating the penetration into small cracks.

*References*
ACI Committee 224R, 1994a, "Control of Cracking in Concrete Structures" *ACI Manual of Concrete Practice*, Detroit, Michigan.

ACI Committee 503R, 1994b, Use of Epoxy Compounds with Concrete", *ACI Manual of Concrete Practice*, Detroit, Michigan.

ASTM, 1990, *Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete, C881-90,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

French, C.W. et al, 1990, "Epoxy Repair Techniques for Moderate Earthquake Damage", *ACI Structural Journal*, July-August 1990, American Concrete Institute, Detroit, Michigan, pp 416-424.

Guedelhoefer, O.C. and A.T. Krauklis, 1986, "To Bond Or Not To Bond", *Concrete International*, August 1986, Detroit, Michigan, pp. 10- 15.

Krauss, P.D, et al, 1995, *Evaluation of Injection Materials for the Repair of Deep Cracks in Concrete Structures*, Technical Report REMR-CS-48, US Army Corps of Engineers, Washington, DC.

Trout, J.F., 1991, "Quality Control on the Injection Project", *Concrete International*, December 1991, American Concrete Institute, Detroit, Michigan, pp 50-52.

| | REPAIR GUIDE | Repair Type: | Structural Repair |
|---|---|---|---|
| SR 2 | CRACK INJECTION - GROUT | Materials: | Concrete,<br>Reinforced Masonry,<br>Unreinforced Masonry |

*Description*
Where cracks along the mortar joints in unreinforced masonry walls produce horizontal offsets in the plane of the wall, the cracks can be repaired by injection of fine grout into the cracks. The grout fills the cracks with material that bonds to the masonry. The grout can also fill voids within the wall, such as in the collar joint. If the bond of the grout is at least equal to the bond of the original mortar, the repaired wall will have at least the same strength and stiffness as the pre-earthquake condition. Since the grout can also fill pre-existing voids within the wall, some improvement may be realized, but should not be expected.

*Repair Materials*
The material used for injection is grout. Removable loose bricks will require mortar. The grout is typically composed of sand, portland cement, lime, and fly ash. Recommended proportions are presented by the City of Los Angeles Rule of General Application (RGA) No. 1-91 (City of LA, 1991). Variations may be required based on local material availability and other requirements.

Other proportions and materials can be used. It is recommended that the materials and proportions be verified for use in the subject application by testing before implementation.

*Equipment*
The following equipment is typically required to perform this work: mixing equipment and pump, pressure-monitoring system. Additional equipment may be necessary, depending on the local conditions.A rotary drill with masonry bits with vacuum chucks is useful in preventing dust from accumulating in the hole.

*Execution*
The walls are prepared by removing loose mortar from open joints. The cracks are flushed with water and then filled with pre-hydrated mortar, which is tooled to match the existing joints. Loose bricks should be removed and reset with mortar.

Injection holes are drilled at head joints or cracked brick, through to the inner wythe in each course, although not entering any air space. Verification ports are drilled 8 to 12 inches to each side of the injection holes. The holes are flushed with water.

Grout is mixed and then pumped into the holes. Typical pressures are 10 to 30 psi. Injection should start at the bottom and work upwards. Grout is injected at a port until grout flows from the adjacent holes. All of the holes along a horizontal joint are filled before moving to the next higher mortar joint.

When the grout has set, the holes are pointed with mortar.

**REPAIR GUIDE**
**continued**

SR 2

*Quality Assurance*
For work within the City of Los Angeles, contractors performing grout injection must be certified by the department of Building and Safety. The certification process is described in the RGA and generally involves a meeting with an Earthquake Repair Inspector and a demonstration of the procedure (City of Los Angeles, 1991).

To perform the grouting properly, the work requires a minimum crew of two certified persons; one as a foreman, and one as a nozzleman. The foreman is responsible for coordination, verifying the pressure of the grout, and batching the grout. The nozzleman is responsible for operating the injection nozzle at the wall.

Before injecting grout, all of the injection and verification holes should be inspected to verify the depth of the holes. During the injection, the grout mixture and injection pressure should be continuously monitored for conformance with the specifications. The verification holes should be watched to verify that the grout is filling the voids. After injecting, core holes should be drilled and visually inspected to verify that the grout filled the voids.

*Limitations*
This procedure has been demonstrated to be effective for cracks ranging from 0.007 inch wide up to ¾ inch wide. Epoxy resins are not recommended for injection into masonry since the properties of the epoxy will not be compatible with those of the masonry. Admixtures such as superplasticizers can aid in the fluidity of the grout so that the grout fills more of the voids.

Existing grout in the collar joints will prevent some dispersion of the injected grout. Crack injection with grout may not restore all of the compressive strength of the masonry, since the grout may not penetrate all of the micro-cracks (Manzouri et al., 1996).

Increasing the pump pressure is not effective at increasing the distance of dispersion of the grout from the injection port (Kariotis and Roselund, 1987). The dispersion can be increased by increasing the fluidity of the grout mixture.

*References*
City of Los Angeles, 1991, "Crack Repair Of Unreinforced Masonry Walls With Grout Injection," *Rule of General Application - RGA No. 1-91.*

Kariotis, J.C and N.A Roselund, 1987, "Repair of Earthquake Damage to Unreinforced Masonry Buildings," *Evaluation and Retrofit of Masonry Structures*, Proceedings of the Second USA-Italy Workshop on Evaluation and Retrofit of Masonry Structures, pp 201-214.

Manzouri, T., M.P. Schuller, P.B. Shing, and B Amadei, 1996, Repair and Retrofit of Unreinforced Masonry Structures, *Earthquake Spectra*, Vol. 12, No. 4, Earthquake Engineering Research Institute, Oakland, California, pp 903-922.

| SR 3 | REPAIR GUIDE<br>SPALL REPAIR | **Repair Type:** | Structural Repair |
|---|---|---|---|
| | | **Materials:** | Concrete<br>Reinforced Masonry,<br>Unreinforced Masonry |

*Description*
Spalls are small sections of wall that become loose or dislodged. Spalls can occur in both concrete and masonry walls. The missing material is replaced with a suitable patch. The material used for the patch must have structural and thermal properties similar to the existing material. The materials and procedures for the patch will also depend on the size and location of the spall and the wall material. These spall repair procedure can be used for concrete, reinforced masonry, infill materials, and unreinforced masonry walls.

*Repair Materials*
For concrete and reinforced masonry walls, the repair material is typically a repair mortar mix, which can be based on inorganic materials, such as Portland cement and latex-modified concrete, or organic materials, such as epoxy and polyester. The mortar mix will include sand and may also include pea gravel. For thick repairs, a mechanical anchorage, using epoxy-embedded dowels, may need to be added to secure the patch.

*Equipment*
The following equipment is typically required:

- Chipping hammer and grinders or concrete saws
- Mixing and placing tools

*Execution*
The concrete or reinforced masonry wall should have all loose material removed with chipping hammers to expose sound substrate. If reinforcing bars are significantly exposed, the concrete or grout should be removed to provide sufficient clearance around the bar for the patch to bond to the full diameter. The perimeter of the spall should be cut with a saw or grinder to create an edge perpendicular to the original surface.

Shallow spall repairs are those that are less than about ¾ inch deep (Krauss, 1994). Deep spalls require correspondingly course aggregate to be added to the repair mortar. For large patches, new steel dowels should be set into the substrate with epoxy and placed so that they extend into the patch.

The substrate should be prepared in accordance with the recommendations of the manufacturer. Separate bonding agents do not generally have to be applied to the surface. The mortar is first scrubbed onto the surface with a stiff broom or brush and then applied with a trowel in lifts. The surface is finished to match the appearance of the original wall surface. The patch is then cured in accordance with manufacturer's recommendations.

**REPAIR GUIDE**
**continued**

SR 3

*Quality Assurance*
Contractors conducting the repairs should be familiar with the repair materials and procedures. If proprietary mortars are specified, the contractor performing the repairs should be certified by the manufacturer of the mortar.

The most critical aspect of the performance of a patch is the bond of the repair material to the substrate (Holl and O'Connor, 1997). The bond strength can be evaluated by a pull-off test, as described in ACI 503R (ACI, 1994). The quality of the bond can also be assessed using nondestructive testing techniques such as Impact Echo or SASW.

*Limitations*
When patching spalls in unreinforced masonry walls and infill frame walls, it may be difficult to obtain repair materials that have properties similar to the masonry. The repairs may also need to consider the changes to the appearance of the wall due to the patch. Mock-up tests should be conducted to verify the applicability of the repairs prior to wide-spread use throughout a building.

These spall repair procedures are suitable for most spalls in concrete or reinforced masonry that are up to ½ cubic foot in volume. Larger spalls in concrete walls may require using formwork and portland cement concrete as the patch material or by the use of shotcrete. Large spalls in reinforced and unreinforced masonry walls may require removing damaged masonry units and replacing them with new, similar units.

Most repair mortars will experience some shrinkage after curing. Therefore, a visible crack may develop around the patch. If the appearance of this crack will be unacceptable, a nonshrink grout mixture should be used or provisions made to conduct cosmetic repairs several days or weeks later.

*References*
ACI Committee 503, 1994, "Use of Epoxy Compounds with Concrete", ACI 503R-93, *ACI Manual of Concrete Practice*, American Concrete Institute, Detroit, Michigan.

Holl, C.H and Scott O'Connor, 1997, "Cleaning and Preparing Concrete before Repair", *Concrete International*, March 1997, American Concrete Institute, Detroit, Michigan, pp 60-63.

Krauss, P.D. 1994, *Repair Materials and Techniques for Concrete Structures in Nuclear Power Plants*, NRC JNC No. B8045, US Nuclear Regulatory Commission, Washington, DC.

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|---|---|---|---|
| | **REPAIR GUIDE** | **Repair Type:** | Structural Repair |
| SR 4 | **REBAR REPLACEMENT** | **Materials:** | Concrete<br>Reinforced Masonry |

*Description*
Mechanical connections can be used in lieu of conventional lapped bar splices to connect or splice two pieces of reinforcing bar. Mechanical connections are particularly useful for connecting new bars to existing bars already embedded in a masonry or concrete structure. They are also useful for repairing damaged structures. Where fractures have occurred in reinforcing bars, or where conventional lapped bar splices have failed, it may be possible to repair the discontinuity by means of a mechanical connection. When repairing certain types of damage, it is necessary to cut out the damaged length of reinforcing bar and to replace it with new bar. In this instance, two mechanical connections are required, where one connection is installed at each end of the replacement bar.

*Repair Materials*
The materials used to make a mechanical connection include the mechanical connection device itself, obtained from the splice manufacturer, and the reinforcing bar being connected. Some mechanical connections use a filler material, such as cementitious grout or a molten metal, typically provided by the splice manufacturer. Most mechanical devices can be used with either ASTM A615 or ASTM A706 reinforcing bar. Certain devices require use of reinforcing bar provided by the splice manufacturer.

Numerous types and configurations of proprietary mechanical connections are available from several different manufacturers. Mechanical connection configurations include:

- Cold-swaged sleeves
- Grout-filled sleeves
- Steel-filled sleeves
- Upset-and-threaded couplers
- Tapered-threaded couplers
- Sleeve with wedge
- Sleeve with lock screws

These and other devices are further described in ACI 439.3R-9, *Mechanical Connections of Reinforcing Bars*, by Committee 439 of the American Concrete Institute (ACI) and also in *Reinforcement Anchorages and Splices*, by the Concrete Reinforcing Steel Institute (CRSI). Detailed technical information is obtained from the proprietary manufacturers.

*Equipment*
Many proprietary connections can be assembled using readily-available hand or power tools, such as ordinary wrenches, calibrated wrenches, or non-impact torque wrenches. Assembly of some connector devices requires special equipment such as an hydraulic press. Tools required vary with the type of connection. The splice manufacturer should be consulted for specific equipment requirements.

**REPAIR GUIDE**
**continued**

SR 4

*Execution*
Unless threaded, the reinforcing bars to be connected need no special preparation beyond a clean-cut end. Connections to bars embedded in masonry require limited removal of some surrounding masonry in order to provide room for insertion of the splice device (but the volume of masonry removed to make a mechanical connection is generally less than that required to make a conventional lapped bar splice). Generally, bars can be set loosely into place, with final alignment made just before completing the splice assembly. The final completion of the connection is carried out in accordance with the instructions provided by the manufacturer.

*Quality Assurance*
Prior to completing final assembly of the connection, it should be verified that the proper length of reinforcing bar has been inserted into the splice device and that the bars are correctly aligned. There are also other quality assurance checks that will vary depending upon the particular type of connection being used. For example, with grout-filled sleeve splices, the slump of the grout mixture should be measured. Again, the manufacturer should be consulted for detailed instruction regarding quality assurance.

For work within the City of Los Angeles, mechanical connection devices must have a General Approval issued by the Department of Building and Safety. As part of the approval process, a series of cyclic tests and tensile strength tests are carried out on sample mechanical connections. The application for General Approval is typically undertaken by the manufacturer of the mechanical connection in advance of any use of the product within the City of Los Angeles. However, the use of non-preapproved devices may be permitted on a case-by-case basis, upon submission of acceptable test data to the Department of Building and Safety.

For mechanical connection of reinforcing bars subject to inelastic cyclic loading, such as bars in or adjacent to a potential or actual plastic-hinge zone, it is also recommended that inelastic cyclic test data be provided by the device manufacturer. The test data should graphically illustrate the load-deflection behavior of the connector-and-bar system under repeated inelastic load cycles, and the post-cycling residual tensile strength of the system should approach or exceed the specified tensile strength of the unspliced reinforcing bar. The proposed ACI Standard includes such testing and strength criteria.

*Limitations*
There are some limitations on the use of mechanical splices, but a limitation for one device may not apply to a different device. Threaded devices are generally not suitable for connections involving existing bars embedded in concrete because the embedded bar cannot be threaded. The physical size of some devices may prevent their use in the occasional application with tight size constraints.

*References*
ACI Committee 439, In Progress, *Standard Specification for Mechanical Reinforcement Splices for Seismic Designs using Energy Dissipation Criteria, ACI 439*, American Concrete Institute, Detroit, Michigan.

ASTM, 1996, *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement, A615/A615M-96a,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM, 1996, *Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement, A706/A706M-96b,* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

| REPAIR GUIDE | Repair Type: | Structural Repair |
|---|---|---|
| **SR 5** WALL REPLACEMENT | Materials: | Concrete<br>Reinforced Masonry,<br>Unreinforced Masonry |

*Description*

Wall replacement requires the removal of an existing wall and replacement with a new wall. The removal of the existing wall should be performed carefully so that the existing reinforcing bars, if present, can be spliced to new reinforcing. The construction of the new wall should match, as closely as possible, the construction of the existing wall.

*Repair Materials*

For concrete replacement walls, the strength of the concrete should be specified to be at least 3000 psi.

For reinforced masonry walls, open-ended units should be specified. These will allow easier installation within the existing structure. The masonry units, mortar, and grout used should conform to the requirements of ACI 530/ASCE 6.

*Equipment*

The equipment used will depend on the construction of the existing wall and the methods used to install the new wall. The following are general equipment items that might be needed for removal and replacement of walls:

- Chipping tools for removal of the wall
- Light chipping tools for preparing the surface of the remaining structure
- Equipment for mixing and placing the concrete, grout, or mortar

*Execution*

If the existing wall is a load-bearing wall, shoring must be installed adjacent to the wall to support the gravity loads while the wall is missing.

The existing wall is carefully removed using saws and chipping tools. Around the perimeter of the opening, care should be exercised to avoid damaging the remaining portions of the structure and to avoid damaging the reinforcing bars, if present.

The surface of the surrounding structure should be prepared for the new material. For concrete and reinforced masonry, the surface of the structure should be roughened to an amplitude of ¼ inch (ACI, 1995).

New reinforcing bars should be spliced to existing bars. If new reinforcing bars are required to be attached to the existing structure, these bars should be anchored to the existing structure by setting them into holes with epoxy. The depth of the hole should be sufficient to develop the strength of the bar. The manufacturer of the epoxy should be consulted for the proper depth of the bar and for the instructions for installing the epoxy.

The new concrete can be placed by forming the wall or by applying shotcrete. Shotcrete application should follow the guidelines for shotcrete overlays (SE1). For cast-in-place walls, concrete is placed through an access hole near the top of the formwork. Additional holes are required for inserting vibrators.

Cast-in-place concrete walls should be wet cured following placement. A curing compound should be used following the wet cure.

The cementitious materials in the new wall will experience drying shrinkage. Since the existing structure will not shrink, the shrinkage will cause a crack to form, typically along the top of the wall. After a significant amount of the drying shrinkage has occurred, typically after two to four months, the crack should be filled with epoxy.

**REPAIR GUIDE**
**continued**

**SR 5**

Following rebar installation, open-ended masonry units can be installed around the reinforcing bars. When the height of the lift of grout is more than 5 feet, holes are left at the top and bottom for installation of grout. If open-ended units are used, access holes are needed every 2 to 3 feet. If closed-end units are used, cleanouts are needed for each cavity. Grout is pumped in through a hole in the top of the wall. The hole at the base is used to verify that the grout has flowed down to the base. After grout is observed at the bottom hole, the hole is sealed to prevent the grout from flowing out of the wall.

*Quality Assurance*
The mix design for the concrete, grout, or mortar should be submitted by the contractor and reviewed prior to use. Concrete core samples should be required from each batch of concrete used. The cores should be tested in accordance with ASTM C39 (ACI, 1995). Masonry units should be tested in accordance with the appropriate standards referenced in ACI 530/ASCE 6-92 (ACI, 1992). Concrete masonry units should be tested using ASTM C140. Brick should be tested using ASTM C 67.

The layout and anchorage of the reinforcing steel should be inspected before forming the concrete or installing the masonry units. A special inspector familiar with epoxy installation should observe installation of the epoxy. A percentage of the epoxy-anchored dowels should be load-tested to at least 50 percent of the yield strength of the bar.

*Limitations*
If the wall to be replaced was constructed with unreinforced masonry, the local building department may not allow replacement with a new unreinforced masonry wall. If the construction of the new wall is substantially different from the previous wall, the strength and stiffness behavior could adversely affect the performance of the building. It may be possible either to negotiate a compromise with the local building department or to introduce a weak link in the wall to prevent its increased stiffness or strength from affecting the behavior of the remainder of the building.

The shrinkage cracks that develop at the top of the wall, if not filled with epoxy or grout, will produce a weakened joint. This weakened joint may cause the behavior mode of the wall to be different from that of the original wall.

*References*
ACI Committee 530/ ASCE Committee 6, 1992, *Specifications for Masonry Structures*, American Society of Civil Engineers, New York, New York.

ACI Committee 318, 1995, *Building Code Requirements for Structural Concrete and Commentary*, American Concrete Institute, Detroit, Michigan.

ASTM, 1997, *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile, C67-97*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM, 1997, *Standard Test Methods of Sampling and Testing Concrete Masonry Units, C140-97*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

| SE 1 | REPAIR GUIDE | Repair Type: | Structural Enhancement |
|---|---|---|---|
| | STRUCTURAL OVERLAY - CONCRETE | Materials: | Concrete<br>Reinforced Masonry,<br>Unreinforced Masonry |

*Description*
Overlay concrete is applied pneumatically (shotcrete) or as a cast-in-place layer onto one or both surfaces of the wall. The concrete is reinforced and attached to the existing structure to enable the concrete to provide supplemental strength to the wall. Two different processes for shotcrete are used in practice: wet mix and dry mix. In the wet-mix process, all ingredients are premixed and the wet mixture delivered to the nozzle where it is shot toward the surface. In the dry-mix process, the dry cement and aggregate are delivered to the nozzle where they are mixed with water while being shot out of the nozzle to the surface (Warner, 1995a).

*Repair Materials*
Portland cement, aggregate, and water are needed. The mixing and proportions will depend on a number of factors, including the process (wet-mix process or dry-mix process)

*Equipment*
The basic equipment includes a mixer, pump or gun, compressor, hoses, and nozzles. (ACI, 1994a, b)

*Execution*
The surface of the existing wall should be prepared by removing loose or damaged material. The surface should be chipped or scarified to avoid abrupt changes in dimension (ACI, 1994b). Reinforcing steel is installed and securely anchored into the existing slabs above and below using dowels set in epoxy.

Before applying the shotcrete, the surface of the existing wall should be prewetted so that specified shotcrete moisture content will not be absorbed into the existing wall (Warner, 1995b). Forms or guide wires are installed to provide alignment control for the application, finishing, and verification of sufficient cover for the reinforcing steel. The nozzleman should direct the shotcrete from the nozzle to the surface with a steady, uninterrupted flow. The angle of the nozzle should be kept as close as possible to perpendicular to the surface of the wall to reduce rebound. A slight angle is required when directing the shotcrete around reinforcing steel to avoid shadowing behind the bars. The shotcrete is applied in several passes starting at the base of the wall, building up the thickness slightly beyond the guide wires.

The shotcrete surface should be finished as required using the guide wires. The shotcrete should then be wet cured for at least one day and preferably seven days (Warner, 1995c). Following the wet cure, a final cure using liquid curing membranes, or other moisture-retaining coverings should be provided.

*Quality Assurance*
The quality of the shotcrete operation is highly dependent on the skill of the nozzleman. Each nozzleman used on a project should be certified and have sufficient experience in similar applications. The nozzlemen can be qualified by completing a large or full-scale mock-up test representing the thickness and congestion conditions that will be encountered.

The mix design for the shotcrete should be submitted by the contractor for review. Small test panels should be prepared in accordance with ASTM C1140, *Standard Practice for Preparing and Testing Specimens from Shotcrete Test Panels* (ASTM, 1997), by each nozzleman at the beginning of each day and at the start of each batch of shotcrete. The sample panels should be cured in the same manner as the walls. Core or cube samples should be removed from each panel and tested to verify the compressive strength and quality.

A qualified inspector should continuously inspect the shotcrete application. The inspector should verify that the materials, placement, finishing, and curing are conducted in accordance with the specifications.

**REPAIR GUIDE**
**continued**

SE 1

*Limitations*
The amount of reinforcing steel in the shotcrete wall should be kept to a minimum. This can be accomplished by using small bars, staggering bars when more than one layer of reinforcing is required (Warner, 1994), and using mechanical splices rather than lap splices. Excessive reinforcing prevents the shotcrete from being placed completely behind the reinforcing steel and also traps the rebound.

Shotcrete bonds well to clean concrete and masonry surfaces. The use of bonding agents is not recommended.

The wet-mix and dry-mix processes have different production requirements and require different skills of the operators. However, both can produce satisfactory results. The dry-mix process is capable of producing higher compressive strength, can be transported longer distances, and produces a material that generally has less shrinkage. The wet-mix process requires less skill of the nozzleman in order to mix uniformly the water with the cement and aggregate and is capable of greater production. The choice of which process to use depends on the capabilities and experience of the contractor.

An apprentice or blow man is recommended to be present to remove rebound, which is the aggregate and cement paste that bounces off the surface during shotcreting. The blowman should prevent the rebound from being mixed in with the shotcrete.

Reinforcing bars should generally not be larger than # 5 bars (ICBO, 1994). However, if larger bar sizes are required, the contractor should be required to perform mockup tests to demonstrate that the shotcrete can effectively be placed around the reinforcing bars. The mock-ups should be tested by core drilling or saw cutting samples at the reinforcing bars. The samples should then be visually analyzed to verify complete coverage of shotcrete around the bars. Full-time inspection of the shotcrete operation in the vicinity of the large bars is also recommended.

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| SE 2 | REPAIR GUIDE<br>STRUCTURAL OVERLAY - COMPOSITE FIBERS | Repair Type: | Structural Enhancement |
|---|---|---|---|
| | | Materials: | Concrete<br>Reinforced Masonry,<br>Unreinforced Masonry |

*Description*

Thin glass or carbon fibers woven into a fabric sheet can be applied to the surface of the wall to enhance the stiffness and strength of the wall. The fibers are generally applied to the surface using an epoxy resin binder and can be oriented in one direction or two directions. The composite fibers are used as tension reinforcing for the wall and can therefore increase the in-plane and out-of-plane strength of the wall.

*Repair Materials*

The typical repair methods use:

- Carbon-fiber or glass-fiber sheets
- Epoxy for bonding the sheets to the wall
- Anchors for attaching composite fiber sheets to substrate
- Surface coatings

*Equipment*

- Surface preparation equipment such as light chipping hammers or sandblasting equipment
- Brushes or rollers are used to apply the epoxy to the wall and to the fabric

*Execution*

Cracks in the walls should be repaired using epoxy or grout injection. Spalls should also be repaired. The wall surfaces are then prepared by lightly sandblasting the surface to the finish required by the manufacturer of the composite fiber.

A thin epoxy binding coat is applied to the surface using rollers. The composite fibers are saturated in epoxy and are pressed into the binder epoxy with a roller. The number of layers and the orientation of the layers depends on the design requirements. Additional epoxy may be applied to fully coat the fibers.

The fabric layers should wrap around the edges of the wall for a distance as recommended by the manufacturer. If a physical interference prevents wrapping the fabric, anchors should be installed through the fabric along the perimeter of the wall and secured to the substrate. The epoxy is then allowed to cure for at least 24 hours, or as recommended by the manufacturer.

After the epoxy has cured, the wall should be covered with a nonstructural coating such as paint, plaster, or wallboard. Special fire-resistant coatings are also available, if needed.

*Quality Assurance*

The behavior of the wall following application of the fiber reinforcement is strongly influenced by the procedures used to apply the composite fibers to the wall. The installation should be carefully monitored to verify that the work is being done in accordance with the manufacturer's recommendations.

**REPAIR GUIDE**
**continued**

**SE 2**

The following items should be checked:

- The surface preparation of the wall to verify that all finishes and loose materials have been removed
- The mixing of the epoxy to verify that the two components have been mixed with the proper proportions
- The installed composite fabric to verify that the fabric has been completely embedded in the epoxy resin
- The overlapping of the fabric sheets and the wrapping of the sheets around corners, to verify that the sheets are anchored as required by the manufacturer
- The curing of the epoxy to ensure conformance with the manufacturer's recommendations

*Limitations*

There are no standards for the design of composite fibers used for the repair of shear walls. Manufacturers of the material can supply references and recommendations for application.

Carbon fibers have a modulus of elasticity and tensile strength that are greater than those of steel. Glass fibers have a lower modulus of elasticity and tensile strength. Both the glass and the carbon fibers exhibit brittle behavior in tension. The failure of the composite fiber system for out-of-plane loading is generally precipitated by debonding of the coating from the wall. Following the debonding, the composite fibers fail in a brittle manner (Reinhorn and Madan, 1995).

When composite fibers are installed in an area that requires a fire rating, a supplemental coating will need to be applied to prevent the epoxy from releasing dangerous fumes when heated.

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| REPAIR GUIDE | Repair Type: | Structural Enhancement |
|---|---|---|
| SE 3 CRACK STITCHING | Materials: | Concrete<br>Reinforced Masonry |

*Description*
When a crack occurs in a lightly-reinforced concrete or reinforced masonry wall, the shear capacity along the crack can be restored and improved by local repair along the crack. This type of repair is most useful for sliding-shear behavior modes when reinforcing bars may be bent or the condition of the crack prevents epoxy from producing an adequate bond. For this repair, new reinforcing bars are inserted across the crack for improved shear resistance.

*Repair Materials*
- Reinforcing bars
- Epoxy for binding the reinforcing bars to the concrete or masonry

*Equipment*
The following equipment is needed:
- Rotary drill to create the holes (Core drills are not recommended)
- Air compressor and brushes
- Mixing and placing equipment for epoxy resin

*Execution*
Holes are drilled across the crack. The holes should be deep enough to develop the strength of the reinforcing bars in the wall and in the substrate above or below. Typically No. 4 or 5 bars are used with a hole depth equal to 18 inches on each side of the crack (ACI, 1994). The holes should intersect the crack at approximately a 45 degree angle. The spacing of the holes and the size of the reinforcing bars should be chosen to provide shear resistance using shear-friction theory for reinforcement inclined to the shear plane, in accordance with ACI 318.

The holes should be thoroughly cleaned by alternate use of compressed air and a brush. Epoxy is placed in the hole and then the reinforcing bar is inserted into the hole. Enough epoxy should be placed in the hole so that some epoxy is forced out of the hole when the reinforcing bar is placed.

*Quality Assurance*
The bond of the epoxy to the reinforcing bars and the substrate are critical to the effectiveness of the repair. For the bond to the substrate to be adequate, the hole must be thoroughly cleaned. This usually involves several cycles of brushing and blowing out the hole. The compressor used for blowing out the hole should be fitted with a filter to prevent oil from mixing with the air. The compressor oil will reduce the bond, if present. Water in the hole can also prevent proper bonding.

The reinforcing bar should not be rotated while it is inserted into the hole. Rotating the bar will break some of the initial bond of the epoxy, which can prevent further bonding.

An inspector should check each hole to verify that it has been adequately cleaned and of the required depth before inserting the reinforcing bar. Each hole should also be inspected following insertion of the bar to verify that the epoxy completely fills the annular space around the bar.

*Limitations*
Inserting dowels across the cracks is only effective if there is sufficient thickness of material above or below the wall to develop the bars. Using bars larger than No. 5 is not usually feasible, since drill bits may not be readily available to achieve the depth of the hole required to develop these larger bars.

Care must be taken to avoid damaging the existing reinforcing bars when drilling the holes for the new reinforcing bars. Rebar detectors should be used to lay out the existing bar placement.

Angle drilling with a rotary bit may be difficult to accomplish precisely by hand. A rig or guide may be needed to confirm that the hole is drilled at the proper angle.

*References*
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# Glossary

**Component** A structural member such as a beam, column, or wall that is an individual part of a structural element

**Cosmetic repairs** Repairs that improve the visual appearance of damage to a component. These repairs may also restore the nonstructural properties of the component, such as weather protection. Any structural benefit is negligible.

**Damaging ground motion** The ground motion that shook the building under consideration and caused resulting damage. This ground motion may or may not have been recorded at the site of the building. In some cases, it may be an estimate of the actual ground motion that occurred. It might consist of estimated time-history records or corresponding response spectra.

**Direct method** The determination of performance restoration measures from the observed damage without relative performance analysis.

**Element** An assembly of structural components (e.g., coupled shear walls, frames)

**Global displacement capacity** The maximum global displacement tolerable for a specific performance level. This global displacement limit is normally controlled by the acceptability of distortion of individual components or a group of components within the structure.

**Global displacement demand** The overall displacement of a representative point on a building subject to a performance ground motion. The representative point is normally taken at the roof level or at the effective center of mass for a given mode of vibration.

**Global structure** The assembly representing all of the structural elements of a building.

**Infilled frame** A concrete or steel frame with concrete or masonry panels installed between the beams and columns

**Nonlinear static procedure** A structural analysis technique in which the structure is modeled as an assembly of components capable of nonlinear force-displacement behavior and subjected to a monotonically increasing lateral load in a specific pattern to generate a global force-displacement capacity curve. The displacement demand is determined with a spectral representation of ground motion, using one of several alternative methods

**Performance ground motion** Hypothetical ground motion consistent with the specified seismic hazard level associated with a specific performance objective. This is characterized by time-history record(s) or corresponding response spectra.

**Performance index** The ratio of the global displacement performance limit to the global displacement demand for a specific seismic performance objective. If this ratio is greater than 1.0, the seismic performance objective is satisfied. This index represents the degree to which the performance meets or falls short of the specific performance objective.

**Performance level** A hypothetical damage state for a building used to establish design seismic performance objectives. The most common performance levels, in order of decreasing amounts of damage, are collapse prevention, life safety, and immediate occupancy.

**Performance loss** 1.0 minus the ratio of the performance index for a damaged building to the performance index in its undamaged state for a specific performance objective. Performance loss ranges from 0 to 1.0 and represents the fraction of seismic performance that was lost during a damaging earthquake.

**Performance objective** A goal consisting of a specific performance level for a building subject to specific seismic hazard.

**Performance restoration measures** Actions that might be implemented for a damaged building that result in future performance equivalent to that of the building in its pre-event state for a specific performance objective. These hypothetical repairs would result in a restored performance index equal to the performance index of the undamaged building.

**Pre-existing condition** Physical evidence of inelastic deformation, damage, or deterioration of a structural component that existed before a damaging earthquake

**Relative performance analysis** An analysis of a building in its damaged and pre-event condition to determine the effects of the damage on the ability of the building to meet specific performance objectives

**Repair** An action taken to address a damaged building component.

**Restoration** The repair of structural components intended to restore the seismic performance of a damaged building to a level equivalent to the pre-event condition of the building.

**Severity of damage** The relative intensity of damage to a particular component, classified as insignificant, slight, moderate, heavy, or extreme.

**Shear wall** A concrete or masonry panel that is connected to the adjacent floor system or a surrounding frame (infilled frame) and that resists in-plane lateral loads.

**Structural enhancements** Repairs that comprise supplemental additions to, or removal and replacement of existing damaged components. They also include the addition of new components in the structure not necessarily at the site of existing damaged components. The intention is to replace rather than restore structural properties of damaged components.

**Structural repairs** Repairs that address damage to components to directly restore structural properties

**Upgrade** The repair of structural components intended to improve the seismic performance of a damaged building to a level better than that of the pre-event building.

# Symbols

$d_c$ Global displacement capacity for pre-event structure for specified performance level

$d_c'$ Global displacement capacity for damaged structure for specified performance level

$d_c^*$ Global displacement capacity for repaired structure for specified performance level

$d_d$ Global displacement demand for pre-event structure for specified seismic hazard

$d_d'$ Global displacement demand for damaged structure for specified seismic hazard

$d_d^*$ Global displacement demand for repaired structure for specified seismic hazard

$d_e$ Maximum global displacement caused by a damaging ground motion

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# ATC-43 Project Participants

## Atc Management


Mr. Christopher Rojahn,
Principal Investigator
Applied Technology Council
555 Twin Dolphin Drive, Suite 550
Redwood City, CA 94065

Mr. Craig Comartin,
Co-PI and Project Director
7683 Andrea Avenue
Stockton, CA 95207


## Technical Management Committee


Prof. Dan Abrams
University of Illinois
1245 Newmark Civil Eng'g. Lab., MC 250
205 North Mathews Avenue
Urbana, IL 61801-2397

Mr. James Hill
James A. Hill & Associates, Inc.
1349 East 28th Street
Signal Hill, CA 90806

Mr. Andrew T. Merovich
A.T. Merovich & Associates, Inc.
1163 Francisco Blvd., Second Floor
San Rafael, CA 94901

Prof. Jack Moehle
Earthquake Engineering Research Center
University of California at Berkeley
1301 South 46th Street
Richmond, CA 94804


## FEMA/PARR Representatives


Mr. Timothy McCormick
PaRR Representative
Dewberry & Davis
8401 Arlington Boulevard
Fairfax, VA 22031-4666

Mr. Mark Doroudian
PaRR Representative
42 Silkwood
Aliso Viejo, CA 92656

Prof. Robert D. Hanson
FEMA Technical Monitor
74 North Pasadena Avenue, CA-1009-DR
Parsons Bldg., West Annex, Room 308
Pasadena, CA 91103

## Materials Working Group

Dr. Joe Maffei, Group Leader
c/o Rutherford & Chekene
303 Second Street, Suite 800 North
San Francisco, CA 94107

Mr. Brian Kehoe, Lead Consultant
Wiss, Janney, Elstner Associates, Inc.
2200 Powell Street, Suite 925
Emeryville, CA 94608

Dr. Greg Kingsley
KL&A of Colorado
805 14th Street
Golden, CO 80401

Mr. Bret Lizundia
Rutherford & Chekene
303 Second Street, Suite 800 North
San Francisco, CA 94107

Prof. John Mander
SUNY at Buffalo
Department of Civil Engineering
212 Ketter Hall
Buffalo, NY 14260

## Analysis Working Group

Prof. Mark Aschheim, Group Leader
University of Illinois at Urbana
2118 Newmark CE Lab
205 North Mathews, MC 250
Urbana, IL 61801

Prof. Mete Sozen, Senior Consultant
Purdue University, School of Engineering
1284 Civil Engineering Building
West Lafayette, IN 47907-1284

## Project Review Panel

Mr. Gregg J. Borchelt
Brick Institute of America
11490 Commerce Park Drive, #300
Reston, VA 20191

Dr. Gene Corley
Construction Technology Labs
5420 Old Orchard Road
Skokie, IL 60077-1030

Mr. Edwin Huston
Smith & Huston
Plaza 600 Building, 6th & Stewart, #620
Seattle, WA 98101

Prof. Richard E. Klingner
University of Texas
Civil Engineering Department
Cockbell Building, Room 4-2
Austin, TX 78705

Mr. Vilas Mujumdar
Office of Regulation Services
Division of State Architect
General Services
1300 I Street, Suite 800
Sacramento, CA 95814

Mr. Hassan A. Sassi
Governors Office of Emergency Services
74 North Pasadena Avenue
Pasadena, CA 91103

Mr. Carl Schulze
Libby Engineers
4452 Glacier Avenue
San Diego, CA 92120

Mr. Daniel Shapiro
SOH & Associates
550 Kearny Street, Suite 200
San Francisco, CA 94108

Prof. James K. Wight
University of Michigan
Department of Civil Engineering
2368 G G Brown
Ann Arbor, MI 48109-2125

Mr. Eugene Zeller
Long Beach Department of Building & Safety
333 W. Ocean Boulevard, Fourth Floor
Long Beach, CA 90802

# Applied Technology Council Projects And Report Information

One of the primary purposes of Applied Technology Council is to develop resource documents that translate and summarize useful information to practicing engineers. This includes the development of guidelines and manuals, as well as the development of research recommendations for specific areas determined by the profession. ATC is not a code development organization, although several of the ATC project reports serve as resource documents for the development of codes, standards and specifications.

Applied Technology Council conducts projects that meet the following criteria:

1. The primary audience or benefactor is the design practitioner in structural engineering.
2. A cross section or consensus of engineering opinion is required to be obtained and presented by a neutral source.
3. The project fosters the advancement of structural engineering practice.

A brief description of several major completed projects and reports is given in the following section. Funding for projects is obtained from government agencies and tax-deductible contributions from the private sector.

**ATC-1:** This project resulted in five papers that were published as part of *Building Practices for Disaster Mitigation, Building Science Series 46*, proceedings of a workshop sponsored by the National Science Foundation (NSF) and the National Bureau of Standards (NBS). Available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151, as NTIS report No. COM-73-50188.

**ATC-2:** The report, *An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings*, was funded by NSF and NBS and was conducted as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation. Available through the ATC office. (Published 1974, 270 Pages)

> ABSTRACT: This study evaluated the applicability and cost of the response spectrum approach to seismic analysis and design that was proposed by various segments of the engineering profession. Specific building designs, design procedures and parameter values were evaluated for future application. Eleven existing buildings of varying dimensions were redesigned according to the procedures.

**ATC-3:** The report, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC-3-06), was funded by NSF and NBS. The second printing of this report, which includes proposed amendments, is available through the ATC office. (Published 1978, amended 1982, 505 pages plus proposed amendments)

> ABSTRACT: The tentative provisions in this document represent the results of a concerted effort by a multi-disciplinary team of 85 nationally recognized experts in earthquake engineering. The provisions serve as the basis for the seismic provisions of the 1988 *Uniform Building Code* and the 1988 and subsequent issues of the *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Buildings*. The second printing of this document contains proposed amendments prepared by a joint committee of the Building Seismic Safety Council (BSSC) and the NBS.

**ATC-3-2:** The project, Comparative Test Designs of Buildings Using ATC-3-06 Tentative Provisions, was funded by NSF. The project consisted of a study to develop and plan a program for making comparative test designs of the ATC-3-06 Tentative Provisions. The project report was written to be used by the Building Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

**ATC-3-4:** The report, *Redesign of Three Multistory Buildings: A Comparison Using ATC-3-06 and 1982 Uniform Building Code Design Provisions*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 112 pages)

> ABSTRACT: This report evaluates the cost and technical impact of using the 1978 ATC-3-06 report, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, as amended by a joint

committee of the Building Seismic Safety Council and the National Bureau of Standards in 1982. The evaluations are based on studies of three existing California buildings redesigned in accordance with the ATC-3-06 Tentative Provisions and the 1982 *Uniform Building Code*. Included in the report are recommendations to code implementing bodies.

**ATC-3-5:** This project, Assistance for First Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council, was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the first phase of its Trial Design Program. The first phase provided for trial designs conducted for buildings in Los Angeles, Seattle, Phoenix, and Memphis.

**ATC-3-6:** This project, Assistance for Second Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council, was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the second phase of its Trial Design Program. The second phase provided for trial designs conducted for buildings in New York, Chicago, St. Louis, Charleston, and Fort Worth.

**ATC-4:** The report, *A Methodology for Seismic Design and Construction of Single-Family Dwellings*, was published under a contract with the Department of Housing and Urban Development (HUD). Available through the ATC office. (Published 1976, 576 pages)

ABSTRACT: This report presents the results of an in-depth effort to develop design and construction details for single-family residences that minimize the potential economic loss and life-loss risk associated with earthquakes. The report: (1) discusses the ways structures behave when subjected to seismic forces, (2) sets forth suggested design criteria for conventional layouts of dwellings constructed with conventional materials, (3) presents construction details that do not require the designer to perform analytical calculations, (4) suggests procedures for efficient plan-checking, and (5) presents recommendations including details and schedules for use in the field by construction personnel and building inspectors.

**ATC-4-1:** The report, *The Home Builders Guide for Earthquake Design*, was published under a contract with HUD. Available through the ATC office. (Published 1980, 57 pages)

ABSTRACT: This report is an abridged version of the ATC-4 report. The concise, easily understood text of the Guide is supplemented with illustrations and 46 construction details. The details are provided to ensure that houses contain structural features that are properly positioned, dimensioned and constructed to resist earthquake forces. A brief description is included on how earthquake forces impact on houses and some precautionary constraints are given with respect to site selection and architectural designs.

**ATC-5:** The report, *Guidelines for Seismic Design and Construction of Single-Story Masonry Dwellings in Seismic Zone 2*, was developed under a contract with HUD. Available through the ATC office. (Published 1986, 38 pages)

ABSTRACT: The report offers a concise methodology for the earthquake design and construction of single-story masonry dwellings in Seismic Zone 2 of the United States, as defined by the 1973 *Uniform Building Code*. The Guidelines are based in part on shaking table tests of masonry construction conducted at the University of California at Berkeley Earthquake Engineering Research Center. The report is written in simple language and includes basic house plans, wall evaluations, detail drawings, and material specifications.

**ATC-6:** The report, *Seismic Design Guidelines for Highway Bridges*, was published under a contract with the Federal Highway Administration (FHWA). Available through the ATC office. (Published 1981, 210 pages)

ABSTRACT: The Guidelines are the recommendations of a team of sixteen nationally recognized experts that included consulting engineers, academics, state and federal agency representatives from throughout the United States. The Guidelines embody several new concepts that were significant departures from then existing design provisions. Included in the Guidelines are an extensive commentary, an example demonstrating the use of the

Guidelines, and summary reports on 21 bridges redesigned in accordance with the Guidelines. The guidelines have been adopted by the American Association of Highway and Transportation Officials as a guide specification.

**ATC-6-1**: The report, *Proceedings of a Workshop on Earthquake Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1979, 625 pages)

ABSTRACT: The report includes 23 state-of-the-art and state-of-practice papers on earthquake resistance of highway bridges. Seven of the twenty-three papers were authored by participants from Japan, New Zealand and Portugal. The Proceedings also contain recommendations for future research that were developed by the 45 workshop participants.

**ATC-6-2**: The report, *Seismic Retrofitting Guidelines for Highway Bridges*, was published under a contract with FHWA. Available through the ATC office. (Published 1983, 220 pages)

ABSTRACT: The Guidelines are the recommendations of a team of thirteen nationally recognized experts that included consulting engineers, academics, state highway engineers, and federal agency representatives. The Guidelines, applicable for use in all parts of the United States, include a preliminary screening procedure, methods for evaluating an existing bridge in detail, and potential retrofitting measures for the most common seismic deficiencies. Also included are special design requirements for various retrofitting measures.

**ATC-7**: The report, *Guidelines for the Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1981, 190 pages)

ABSTRACT: Guidelines are presented for designing roof and floor systems so these can function as horizontal diaphragms in a lateral force resisting system. Analytical procedures, connection details and design examples are included in the Guidelines.

**ATC-7-1**: The report, *Proceedings of a Workshop of Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1980, 302 pages)

ABSTRACT: The report includes seven papers on state-of-the-practice and two papers on recent research. Also included are recommendations for future research that were developed by the 35 workshop participants.

**ATC-8**: This report, *Proceedings of a Workshop on the Design of Prefabricated Concrete Buildings for Earthquake Loads*, was funded by NSF. Available through the ATC office. (Published 1981, 400 pages)

ABSTRACT: The report includes eighteen state-of-the-art papers and six summary papers. Also included are recommendations for future research that were developed by the 43 workshop participants.

**ATC-9**: The report, *An Evaluation of the Imperial County Services Building Earthquake Response and Associated Damage*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 231 pages)

ABSTRACT: The report presents the results of an in-depth evaluation of the Imperial County Services Building, a 6-story reinforced concrete frame and shear wall building severely damaged by the October 15, 1979 Imperial Valley, California, earthquake. The report contains a review and evaluation of earthquake damage to the building; a review and evaluation of the seismic design; a comparison of the requirements of various building codes as they relate to the building; and conclusions and recommendations pertaining to future building code provisions and future research needs.

**ATC-10**: This report, *An Investigation of the Correlation Between Earthquake Ground Motion and Building Performance*, was funded by the U.S. Geological Survey (USGS). Available through the ATC office. (Published 1982, 114 pages)

ABSTRACT: The report contains an in-depth analytical evaluation of the ultimate or limit capacity of selected representative building framing types, a discussion of the factors affecting the seismic performance of buildings, and a summary and comparison of seismic design and seismic risk parameters currently in widespread use.

**ATC-10-1**: This report, *Critical Aspects of Earthquake Ground Motion and Building Damage Potential*, was co-funded by the USGS and the NSF. Available through the ATC office. (Published 1984, 259 pages)

ABSTRACT: This document contains 19 state-of-the-art papers on ground motion, structural response, and structural design issues presented by prominent engineers and earth scientists in an ATC seminar. The main theme of the papers is to identify the critical aspects of ground motion and building performance that currently are not being considered in building design. The report also contains conclusions and recommendations of working groups convened after the Seminar.

**ATC-11**: The report, *Seismic Resistance of Reinforced Concrete Shear Walls and Frame Joints: Implications of Recent Research for Design Engineers*, was published under a grant from NSF. Available through the ATC office. (Published 1983, 184 pages)

ABSTRACT: This document presents the results of an in-depth review and synthesis of research reports pertaining to cyclic loading of reinforced concrete shear walls and cyclic loading of joint reinforced concrete frames. More than 125 research reports published since 1971 are reviewed and evaluated in this report. The preparation of the report included a consensus process involving numerous experienced design professionals from throughout the United States. The report contains reviews of current and past design practices, summaries of research developments, and in-depth discussions of design implications of recent research results.

**ATC-12**: This report, *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1982, 270 pages)

ABSTRACT: The report contains summaries of all aspects and innovative design procedures used in New Zealand as well as comparison of United States and New Zealand design practice. Also included are research recommendations developed at a 3-day workshop in New Zealand attended by 16 U.S. and 35 New Zealand bridge design engineers and researchers.

**ATC-12-1**: This report, *Proceedings of Second Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 272 pages)

ABSTRACT: This report contains written versions of the papers presented at this 1985 Workshop as well as a list and prioritization of workshop recommendations. Included are summaries of research projects being conducted in both countries as well as state-of-the-practice papers on various aspects of design practice. Topics discussed include bridge design philosophy and loadings; design of columns, footings, piles, abutments and retaining structures; geotechnical aspects of foundation design; seismic analysis techniques; seismic retrofitting; case studies using base isolation; strong-motion data acquisition and interpretation; and testing of bridge components and bridge systems.

**ATC-13**: The report, *Earthquake Damage Evaluation Data for California*, was developed under a contract with the Federal Emergency Management Agency (FEMA). Available through the ATC office. (Published 1985, 492 pages)

ABSTRACT: This report presents expert-opinion earthquake damage and loss estimates for industrial, commercial, residential, utility and transportation facilities in California. Included are damage probability matrices for 78 classes of structures and estimates of time required to restore damaged facilities to pre-earthquake usability. The report also describes the inventory information essential for estimating economic losses and the methodology used to develop loss estimates on a regional basis.

**ATC-14**: The report, *Evaluating the Seismic Resistance of Existing Buildings*, was developed under a grant from the NSF. Available through the ATC office. (Published 1987, 370 pages)

ABSTRACT: This report, written for practicing structural engineers, describes a methodology for performing preliminary and detailed building seismic evaluations. The report contains a state-of-practice review; seismic loading criteria; data collection procedures; a detailed description of the building classification system; preliminary and detailed analysis procedures; and example case studies, including nonstructural considerations.

**ATC-15**: The report, *Comparison of Seismic Design Practices in the United States and Japan*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 317 pages)

ABSTRACT: The report contains detailed technical papers describing design practices in the United States and Japan as well as recommendations emanating from a joint U.S.-Japan workshop held in Hawaii in March, 1984. Included are detailed descriptions of new seismic design methods for buildings in Japan and case studies of the design of specific buildings (in both countries). The report also contains an overview of the history and objectives of the Japan Structural Consultants Association.

**ATC-15-1**: The report, *Proceedings of Second U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices*, was published under a grant from NSF. Available through the ATC office. (Published 1987, 412 pages)

ABSTRACT: This report contains 23 technical papers presented at this San Francisco workshop in August, 1986, by practitioners and researchers from the U.S. and Japan. Included are state-of-the-practice papers and case studies of actual building designs and information on regulatory, contractual, and licensing issues.

**ATC-15-2**: The report, *Proceedings of Third U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1989, 358 pages)

ABSTRACT: This report contains 21 technical papers presented at this Tokyo, Japan, workshop in July, 1988, by practitioners and researchers from the U.S., Japan, China, and New Zealand. Included are state-of-the-practice papers on various topics, including braced steel frame buildings, beam-column joints in reinforced concrete buildings, summaries of comparative U. S. and Japanese design, and base isolation and passive energy dissipation devices.

**ATC-15-3**: The report, *Proceedings of Fourth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1992, 484 pages)

ABSTRACT: This report contains 22 technical papers presented at this Kailua-Kona, Hawaii, workshop in August, 1990, by practitioners and researchers from the United States, Japan, and Peru. Included are papers on postearthquake building damage assessment; acceptable earth-quake damage; repair and retrofit of earthquake damaged buildings; base-isolated buildings, including Architectural Institute of Japan recommendations for design; active damping systems; wind-resistant design; and summaries of working group conclusions and recommendations.

**ATC-15-4:** The report, *Proceedings of Fifth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1994, 360 pages)

ABSTRACT: This report contains 20 technical papers presented at this San Diego, California workshop in September, 1992. Included are papers on performance goals/acceptable damage in seismic design; seismic design procedures and case studies; construction influences on design; seismic isolation and passive energy dissipation; design of irregular structures; seismic evaluation, repair and upgrading; quality control for design and construction; and summaries of working group discussions and recommendations.

**ATC-16**: This project, Development of a 5-Year Plan for Reducing the Earthquake Hazards Posed by Existing Nonfederal Buildings, was funded by FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering

Research Institute. The project involved a workshop in Phoenix, Arizona, where approximately 50 earthquake specialists met to identify the major tasks and goals for reducing the earthquake hazards posed by existing non-federal buildings nationwide. The plan was developed on the basis of nine issue papers presented at the workshop and workshop working group discussions. The Workshop Proceedings and Five-Year Plan are available through the Federal Emergency Management Agency, 500 "C" Street, S.W., Washington, DC 20472.

**ATC-17**: This report, *Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 478 pages)

ABSTRACT: The report contains 42 papers describing the state-of-the-art and state-of-the-practice in base-isolation and passive energy-dissipation technology. Included are papers describing case studies in the United States, applications and developments worldwide, recent innovations in technology development, and structural and ground motion issues. Also included is a proposed 5-year research agenda that addresses the following specific issues: (1) strong ground motion; (2) design criteria; (3) materials, quality control, and long-term reliability; (4) life cycle cost methodology; and (5) system response.

**ATC-17-1**: This report, *Proceedings of a Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control,* was published under a grant from NSF. Available through the ATC office. (Published 1993, 841 pages)

ABSTRACT: The 2-volume report documents 70 technical papers presented during a two-day seminar in San Francisco in early 1993. Included are invited theme papers and competitively selected papers on issues related to seismic isolation systems, passive energy dissipation systems, active control systems and hybrid systems.

**ATC-18**: The report, *Seismic Design Criteria for Bridges and Other Highway Structures: Current and Future*, was published under a contract from the Multidisciplinary Center for Earthquake Engineering Research (formerly NCEER), with funding from the Federal Highway Administration. Available through the ATC office. (Published 1997, 152 pages)

ABSTRACT: This report documents the findings of a 4-year project to review and assess current seismic design criteria for new highway construction. The report addresses performance criteria, importance classification, definitions of seismic hazard for areas where damaging earthquakes have longer return periods, design ground motion, duration effects, site effects, structural response modification factors, ductility demand, design procedures, foundation and abutment modeling, soil-structure interaction, seat widths, joint details and detailing reinforced concrete for limited ductility in areas with low-to-moderate seismic activity. The report also provides lengthy discussion on future directions for code development and recommended research and development topics.

**ATC-19**: The report, *Structural Response Modification Factors* was funded by NSF and NCEER. Available through the ATC office. (Published 1995, 70 pages)

ABSTRACT: This report addresses structural response modification factors (R factors), which are used to reduce the seismic forces associated with elastic response to obtain design forces. The report documents the basis for current R values, how R factors are used for seismic design in other countries, a rational means for decomposing R into key components, a framework (and methods) for evaluating the key components of R, and the research necessary to improve the reliability of engineered construction designed using R factors.

**ATC-20**: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract from the California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. Available through the ATC office (Published 1989, 152 pages)

ABSTRACT: This report provides procedures and guidelines for making on-the-spot evaluations and decisions regarding continued use and occupancy of earthquake damaged buildings. Written specifically for volunteer structural engineers and building inspectors, the report includes rapid and detailed evaluation procedures for inspecting buildings and posting them as "inspected" (apparently safe), "limited entry" or "unsafe". Also included are special procedures for evaluation of essential buildings (e.g., hospitals), and evaluation procedures for nonstructural elements, and geotechnical hazards.

**ATC-20-1**: The report, *Field Manual: Postearthquake Safety Evaluation of Buildings*, was developed under a contract from OES and OSHPD. Available through the ATC office (Published 1989, 114 pages)

ABSTRACT: This report, a companion Field Manual for the ATC-20 report, summarizes the postearthquake safety evaluation procedures in brief concise format designed for ease of use in the field.

**ATC-20-2:** The report, *Addendum to the ATC-20 Postearthquake Building Safety Procedures* was published under a grant from the NSF and funded by the USGS. Available through the ATC office. (Published 1995, 94 pages)

ABSTRACT: This report provides updated assessment forms, placards, and procedures that are based on an in-depth review and evaluation of the widespread application of the ATC-20 procedures following five earthquakes occurring since the initial release of the ATC-20 report in 1989.

**ATC-20-3:** The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R. P. Gallagher Associates. Available through the ATC office. (Published 1996, 295 pages)

ABSTRACT: This report contains 53 case studies using the ATC-20 Rapid Evaluation procedure. Each case study is illustrated with photos and describes how a building was inspected and evaluated for life safety, and includes a completed safety assessment form and placard. The report is intended to be used as a training and reference manual for building officials, building inspectors, civil and structural engineers, architects, disaster workers, and others who may be asked to perform safety evaluations after an earthquake.

**ATC-20-T:** The report, *Postearthquake Safety Evaluation of Buildings Training Manual* was developed under a contract with FEMA. Available through the ATC office. (Published 1993, 177 pages; 160 slides)

ABSTRACT: This training manual is intended to facilitate the presentation of the contents of the ATC-20 and ATC-20-1. The training materials consist of 160 slides of photographs, schematic drawings and textual information and a companion training presentation narrative coordinated with the slides. Topics covered include: posting system; evaluation procedures; structural basics; wood frame, masonry, concrete, and steel frame structures; nonstructural elements; geotechnical hazards; hazardous materials; and field safety.

**ATC-21**: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, was developed under a contract from FEMA. Available through the ATC office. (Published 1988, 185 pages)

ABSTRACT: This report describes a rapid visual screening procedure for identifying those buildings that might pose serious risk of loss of life and injury, or of severe curtailment of community services, in case of a damaging earthquake. The screening procedure utilizes a methodology based on a "sidewalk survey" approach that involves identification of the primary structural load resisting system and building materials, and assignment of a basic structural hazards score and performance modification factors based on observed building characteristics. Application of the methodology identifies those buildings that are potentially hazardous and should be analyzed in more detail by a professional engineer experienced in seismic design.

**ATC-21-1**: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation*, was developed under a contract from FEMA. Available through the ATC office. (Published 1988, 137 pages)

ABSTRACT: Included in this report are (1) a review and evaluation of existing procedures; (2) a listing of attributes considered ideal for a rapid visual screening procedure; and (3) a technical discussion of the recommended rapid visual screening procedure that is documented in the ATC-21 report.

**ATC-21-2**: The report, *Earthquake Damaged Buildings: An Overview of Heavy Debris and Victim Extrication*, was developed under a contract from FEMA. (Published 1988, 95 pages)

ABSTRACT: Included in this report, a companion volume to the ATC-21 and ATC-21-1 reports, is state-of-the-art information on (1) the identification of those buildings that might collapse and trap victims in debris or generate debris of such a size that its handling would require special or heavy lifting equipment; (2) guidance in identifying these types of buildings, on the basis of their major exterior features, and (3) the types and life capacities of equipment required to remove the heavy portion of the debris that might result from the collapse of such buildings.

**ATC-21-T:** The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual* was developed under a contract with FEMA. Available through the ATC office. (Published 1996, 135 pages; 120 slides)

ABSTRACT: This training manual is intended to facilitate the presentation of the contents of the ATC-21 report. The training materials consist of 120 slides and a companion training presentation narrative coordinated with the slides. Topics covered include: description of procedure, building behavior, building types, building scores, occupancy and falling hazards, and implementation.

**ATC-22**: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, was developed under a contract from FEMA. Available through the ATC office. (Originally published in 1989; revised by BSSC and published as the *NEHRP Handbook for Seismic Evaluation of Existing Buildings* in 1992, 211 pages)

ABSTRACT: This handbook provides a methodology for seismic evaluation of existing buildings of different types and occupancies in areas of different seismicity throughout the United States. The methodology, which has been field tested in several programs nationwide, utilizes the information and procedures developed for and documented in the ATC-14 report. The handbook includes checklists, diagrams, and sketches designed to assist the user.

**ATC-22-1**: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract from FEMA. (Published 1989, 160 pages)

ABSTRACT: Included in this report, a companion volume to the ATC-22 report, are (1) a review and evaluation of existing buildings seismic evaluation methodologies; (2) results from field tests of the ATC-14 methodology; and (3) summaries of evaluations of ATC-14 conducted by the National Center for Earthquake Engineering Research (State University of New York at Buffalo) and the City of San Francisco.

**ATC-23A**: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part A: Survey Description, Summary of Results, Data Analysis and Interpretation*, was developed under a contract from the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through the ATC office. (Published 1991, 58 pages)

ABSTRACT: This report summarizes results from a seismic survey of 490 California acute care hospitals. Included are a description of the survey procedures and data collected, a summary of the data, and an illustrative discussion of data analysis and interpretation that has been provided to demonstrate potential applications of the ATC-23 database.

**ATC-23B**: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part B: Raw Data*, is a companion document to the ATC-23A Report and was developed under the above-mentioned contract from OSHPD. Available through the ATC office. (Published 1991, 377 pages)

ABSTRACT: Included in this report are tabulations of raw general site and building data for 490 acute care hospitals in California.

**ATC-24**: The report, *Guidelines for Seismic Testing of Components of Steel Structures*, was jointly funded by the American Iron and Steel Institute (AISI), American Institute of Steel Construction (AISC), National Center for Earthquake Engineering Research (NCEER), and NSF. Available through the ATC office. (Published 1992, 57 pages)

ABSTRACT: This report provides guidance for most cyclic experiments on components of steel structures for the purpose of consistency in experimental procedures. The report contains recommendations and companion commentary pertaining to loading histories, presentation of test results, and other aspects of experimentation. The recommendations are written specifically for experiments with slow cyclic load application.

**ATC-25**: The report, *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous United States*, was developed under a contract from FEMA. Available through the ATC office. (Published 1991, 440 pages)

ABSTRACT: Documented in this report is a national overview of lifeline seismic vulnerability and impact of disruption. Lifelines considered include electric systems, water systems, transportation systems, gas and liquid fuel supply systems, and emergency service facilities (hospitals, fire and police stations). Vulnerability estimates and impacts developed are presented in terms of estimated first approximation direct damage losses and indirect economic losses.

**ATC-25-1**: The report, *A Model Methodology for Assessment of Seismic Vulnerability and Impact of Disruption of Water Supply Systems*, was developed under a contract from FEMA. Available through the ATC office. (Published 1992, 147 pages)

ABSTRACT: This report contains a practical methodology for the detailed assessment of seismic vulnerability and impact of disruption of water supply systems. The methodology has been designed for use by water system operators. Application of the methodology enables the user to develop estimates of direct damage to system components and the time required to restore damaged facilities to pre-earthquake usability. Suggested measures for mitigation of seismic hazards are also provided.

**ATC-28**: The report, *Development of Recommended Guidelines for Seismic Strengthening of Existing Buildings, Phase I: Issues Identification and Resolution*, was developed under a contract with FEMA. Available through the ATC office. (Published 1992, 150 pages)

ABSTRACT: This report identifies and provides resolutions for issues that will affect the development of guidelines for the seismic strengthening of existing buildings. Issues addressed include: implementation and format, coordination with other efforts, legal and political, social, economic, historic buildings, research and technology, seismicity and mapping, engineering philosophy and goals, issues related to the development of specific provisions, and nonstructural element issues.

**ATC-29**: The report, *Proceedings of a Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1992, 470 pages)

ABSTRACT: These Proceedings contain 35 papers describing state-of-the-art technical information pertaining to the seismic design and performance of equipment and nonstructural elements in buildings and industrial structures. The papers were presented at a seminar in Irvine, California in 1990. Included are papers describing current practice, codes and regulations; earthquake performance; analytical and experimental investigations; development of new seismic qualification methods; and research, practice, and code development needs for specific elements and systems. The report also includes a summary of a proposed 5-year research agenda for NCEER.

**ATC-29-1**: The report, *Proceedings Of Seminar On Seismic Design, Retrofit, And Performance Of Nonstructural Components*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1998, 518 pages)

ABSTRACT: These Proceedings contain 38 papers presenting current research, practice, and informed thinking pertinent to seismic design, retrofit, and performance of nonstructural components. The papers were presented at a seminar in San Francisco, California, in 1998. Included are papers describing observed performance in recent earthquakes; seismic design codes, standards, and procedures for commercial and institutional buildings; seismic design issues relating to industrial and hazardous material facilities; design, analysis, and test-

ing; and seismic evaluation and rehabilitation of conventional and essential facilities, including hospitals.

**ATC-30**: The report, *Proceedings of Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of 1985 Chile and Mexico Earthquakes*, was developed under a grant from the NSF. Available through the ATC office. (Published 1991, 113 pages)

ABSTRACT: This report documents the findings of a 1990 technology transfer workshop in San Diego, California, co-sponsored by ATC and the Earthquake Engineering Research Institute. Included in the report are invited papers and working group recommendations on geotechnical issues, structural response issues, architectural and urban design considerations, emergency response planning, search and rescue, and reconstruction policy issues.

**ATC-31**: The report, *Evaluation of the Performance of Seismically Retrofitted Buildings*, was developed under a contract from the National Institute of Standards and Technology (NIST, formerly NBS) and funded by the USGS. Available through the ATC office. (Published 1992, 75 pages)

ABSTRACT: This report summarizes the results from an investigation of the effectiveness of 229 seismically retrofitted buildings, primarily unreinforced masonry and concrete tilt-up buildings. All buildings were located in the areas affected by the 1987 Whittier Narrows, California, and 1989 Loma Prieta, California, earthquakes.

**ATC-32**: The report, *Improved Seismic Design Criteria for California Bridges: Provisional Recommendations,* was funded by the California Department of Transportation (Caltrans). Available through the ATC office. (Published 1996, 215 Pages)

ABSTRACT: This report provides recommended revisions to the current *Caltrans Bridge Design Specifications* (BDS) pertaining to seismic loading, structural response analysis, and component design. Special attention is given to design issues related to reinforced concrete components, steel components, foundations, and conventional bearings. The recommendations are based on recent research in the field of bridge seismic design and the performance of Caltrans-designed bridges in the 1989 Loma Prieta and other recent California earthquakes.

**ATC-34:** The report, *A Critical Review of Current Approaches to Earthquake Resistant Design,* was developed under a grant from NCEER and NSF. Available through the ATC office. (Published, 1995, 94 pages)

ABSTRACT. This report documents the history of U. S. codes and standards of practice, focusing primarily on the strengths and deficiencies of current code approaches. Issues addressed include: seismic hazard analysis, earthquake collateral hazards, performance objectives, redundancy and configuration, response modification factors (*R* factors), simplified analysis procedures, modeling of structural components, foundation design, nonstructural component design, and risk and reliability. The report also identifies goals that a new seismic code should achieve.

**ATC-35**: This report, *Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice* was developed under a contract with the USGS. Available through the ATC office. (Published 1996, 120 pages)

ABSTRACT: The report provides a program of recommended "technology transfer" activities for the USGS; included are recommendations pertaining to management actions, communications with practicing engineers, and research activities to enhance development and transfer of information that is vital to engineering practice.

**ATC-35-1**: The report, *Proceedings of Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1994, 478 pages)

ABSTRACT: These Proceedings contain 22 technical papers describing state-of-the-art information on regional earthquake risk (focused on five specific regions--California, Pacific Northwest, Central United States, and northeastern North America); new techniques for estimating strong ground motions as a function of earthquake source, travel path, and site parameters; and new developments specifically applicable to geotechnical engineering and the seismic design of buildings and bridges.

**ATC-37:** The report, *Review of Seismic Research Results on Existing Buildings*, was developed in conjunction with the Structural Engineers Association of California and California Universities for Research in Earthquake Engineering under a contract from the California Seismic Safety Commission (SSC). Available through the Seismic Safety Commission as Report SSC 94-03. (Published, 1994, 492 pages)

ABSTRACT. This report describes the state of knowledge of the earthquake performance of nonductile concrete frame, shear wall, and infilled buildings. Included are summaries of 90 recent research efforts with key results and conclusions in a simple, easy-to-access format written for practicing design professionals.

**ATC-40:** The report, *Seismic Evaluation and Retrofit of Concrete Buildings*, was developed under a contract from the California Seismic Safety Commission. Available through the ATC office. (Published, 1996, 612 pages)

ABSTRACT. This 2-volume report provides a state-of-the-art methodology for the seismic evaluation and retrofit of concrete buildings. Specific guidance is provided on the following topics: performance objectives; seismic hazard; determination of deficiencies; retrofit strategies; quality assurance procedures; nonlinear static analysis procedures; modeling rules; foundation effects; response limits; and nonstructural components. In 1997 this report received the Western States Seismic Policy Council "Overall Excellence and New Technology Award."

**ATC-44:** The report, *Hurricane Fran, South Carolina, September 5, 1996: Reconnaissance Report*, is available through the ATC office. (Published 1997, 36 pages.)

ABSTRACT: This report represents ATC's expanded mandate into structural engineering problems arising from wind storms and coastal flooding. It contains information on the causative hurricane; coastal impacts, including storm surge, waves, structural forces and erosion; building codes; observations and interpretations of damage; and lifeline performance. Conclusions address man-made beach nourishment, the effects of missile-like debris, breaches in the sandy barrier islands, and the timing and duration of such investigations.

**ATC-R-1:** The report, *Cyclic Testing of Narrow Plywood Shear Walls*, was developed with funding from the Henry J. Degenkolb Memorial Endowment Fund of the Applied Technology Council. Available through the ATC office (Published 1995, 64 pages)

ABSTRACT: This report documents ATC's first self-directed research program: a series of static and dynamic tests of narrow plywood wall panels having the standard 3.5-to-1 height-to-width ratio and anchored to the sill plate using typical bolted, 9-inch, 5000-lb. capacity hold-down devices. The report provides a description of the testing program and a summary of results, including comparisons of drift ratios found during testing with those specified in the seismic provisions of the 1991 *Uniform Building Code*.

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